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Intervention for Recovery after Accidents

Application of Emergency Reference Levels of Dose in Emergency Planning and Response

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VOLUME 8 NO 1 1997

National Radiological Protection Board
Chilton, Didcot, Oxon OX11 0RQ

The National Radiological Protection Board was created by the Radiological Protection Act 1970. The functions of the Board are to give advice, to conduct research, and to provide technical services in the field of protection against both ionising and non-ionising radiations.

In 1977 the Board received Directions under the Radiological Protection Act which require it to give advice on the acceptability to and the application in the UK, of standards recommended by international or intergovernmental bodies, and to specify emergency reference levels (ERLs) of dose for limiting radiation doses in accident situations.

Documents of the NRPB contain both the formal advice of the Board on standards of protection as well as guidance on their application in practice.

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INTERVENTION FOR RECOVERY AFTER ACCIDENTS

ABSTRACT

The purpose of this document is to provide a framework for developing protective strategies in the longer term following an accidental release of radionuclides to the offsite environment. This advice covers all forms and scales of accidental release, including releases from nuclear sites and reactors, weapons accidents, and damaged industrial or medical sealed sources. The countermeasures considered are those intended to protect the public from external irradiation from radionuclides deposited in the environment, from the inhalation of resuspended radionuclides, and from inadvertent ingestion of radionuclides resulting from contact with contaminated surfaces. The Board terms these recovery countermeasures. They can be broadly grouped as either decontamination measures (ie measures that deal directly with the radionuclides, whether by removing them, shielding them or physically or chemically bonding them) or as restricted access measures (ie measures that reduce exposure by restricting individuals' access to contaminated areas). This guidance includes quantitative criteria for the introduction of recovery countermeasures and a summary of the relative costs and benefits of a range of specific measures.

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INTRODUCTION

1 The Board is responsible for providing advice on criteria for accident response and accident response planning. Formal guidance has been published on the general principles for intervention[1], on emergency reference levels (ERLs) of dose for the emergency countermeasures of sheltering, evacuation and the issue of stable iodine[2], and on the radiological effectiveness of food and water restrictions[3]. In addition, guidance has been provided on the application of ERLs in the development of emergency plans[4]. The Board has not yet published formal advice on the implementation of countermeasures to protect against possible long-term exposures from external irradiation from radionuclides deposited in the environment, from the inhalation of resuspended radionuclides, and from inadvertent ingestion of radionuclides resulting from contact with contaminated surfaces. Such interventions are here termed recovery countermeasures. The measures most likely to reduce such doses comprise the decontamination of land and property, and the restriction of access to contaminated areas (in the extreme, total prohibition of access to an area for weeks, months or years). As with emergency countermeasures, recovery countermeasures need to be both justified and optimised, in accordance with both national[1] and international[5] advice. The purpose of this document is to prepare a framework for decisions on recovery countermeasures in the UK. This advice covers all forms and scales of accidental release, including releases from nuclear sites and reactors, weapons accidents, and damaged industrial or medical sealed sources.

2 The advice developed on emergency countermeasures[2] identified a number of factors relevant to such decisions, which could be grouped under three broad headings: health, monetary cost and social consequences. In particular, it was recognised as important to incorporate an understanding of the social and psychological consequences of implementing a given countermeasures strategy. These consequences may be more important for decisions on recovery countermeasures. In this case, strong tensions may develop between different groups concerning what is both acceptable and practicable. A successful strategy will need to address these issues. For example, measures may be taken for reassurance purposes that provide little benefit in terms of averting doses, or countermeasures may be supported by appropriate information campaigns or compensatory measures. Whatever the protective decisions, it is of paramount importance that the needs and concerns of the local communities are addressed alongside purely radiological considerations. The provision of detailed advice on how best to address social issues is beyond the scope of this document. However, the intent of the radiological protection advice developed here is that it provides a framework within which such issues can be addressed.

LONG-TERM EXPOSURE PATHWAYS

3 A booklet published by the Health and Safety Executive describes the arrangements for responding to nuclear emergencies in the UK and summarises the regulation of safety standards used in the design, construction, operation and maintenance of nuclear installations, and applied to the associated transport activities[6]. Similar arrangements are in place for Ministry of Defence operations. The safety standards reduce to very low levels the risk of accidents which could have consequences for the general public. Moreover, the greater the potential hazard the more stringent are the safety precautions and the required

standards. Therefore, the most likely outcome of even a serious malfunction at a nuclear plant would be that no member of the public would be harmed at all, because at least one of the safety systems would prevent the accident developing to the stage where a significant release of radionuclides took place. Nevertheless, prudence requires the preparation of plans for dealing with accidents resulting in consequences for the public.

4 Emergency planning is based on a detailed safety analysis for each plant or operation. These analyses identify a spectrum of accidents which can reasonably be foreseen, termed 'design basis' accidents. The analysis of these accidents forms the basis for determining the level of planning required for emergency countermeasures, such as evacuation and sheltering. Studies carried out for the UK Nuclear Emergency Planning Liaison Group demonstrated that, even following a large design basis accident, the long-term radiation health consequences for the public would be small[7]. Therefore, even if short-term countermeasures such as sheltering or evacuation were advised following an accident, it is unlikely that further countermeasures (other than possibly food restrictions) would be required on a continuing basis. In the extremely unlikely event of the occurrence of an accident even larger than that considered in the design basis, it is possible that levels of contamination in the environment could result in chronic exposures to a resident population that would warrant intervention to reduce them. In this case, the likely harms and benefits of different intervention strategies would need to be assessed, in the light both of the level of risk posed by such exposures and also of the need to facilitate a return to normal lifestyles within the affected population.

5 The main potential pathways of exposure in the longer term after such accidents are external irradiation from radionuclides deposited in the environment, inhalation of resuspended radionuclides and ingestion of contaminated foods. (Inadvertent ingestion from contact with contaminated materials would only in very unusual circumstances form a significant potential dose pathway.) Protection against the ingestion of contaminated foods can be provided by appropriate controls on their production and marketing. This is the responsibility of the Agricultural Departments, and is subject to European Commission (EC) regulation[8,9,10]. Exposure from contaminated foods may be dealt with quite separately from other exposures, and the Board has already published advice on this topic[3]. Therefore, no further consideration will be given to the food exposure pathway in this document.

6 The pattern of environmental contamination resulting from an accident would depend strongly upon the characteristics of the accident. In general, a release to atmosphere would result in widespread contamination (albeit probably at a relatively low level), while a release to water, or a localised 'spill', would be more limited in geographical extent. For a release to atmosphere particularly, the weather conditions at the time of the accident would also strongly influence the pattern of contamination. Once deposited in the environment, the risk posed by the radionuclides would depend upon many factors, including the amounts present, their radioactive halflives, their mobility in the environment and the amount of time people spent in their proximity. Generally, in the absence of protective countermeasures, the exposure rate would be highest immediately after deposition and would reduce thereafter as the radionuclides migrated from exposed surfaces (eg dispersal by water or migration downwards in the ground), although it is possible that subsequent increases in exposure rate would occur owing to the movement of radionuclides into closer proximity with people. In terms of individual risk, the primary

concern for beta/gamma-emitting radionuclides would be external irradiation, whereas that for alpha-emitting radionuclides (eg plutonium-239) would be resuspension[11,12]. However, where activities were planned that were particularly prone to raising dust (eg for workers carrying out some decontamination measures), it would be important to consider the resuspension pathway for all types of deposited radionuclides.

PURPOSE OF RECOVERY COUNTERMEASURES

7 In the context of this document, it is helpful to define two accident time phases, the emergency phase and the recovery phase. The emergency phase is the period during which emergency (ie urgent) countermeasures would be required to protect individuals against short-term, relatively high risks. The recovery phase is the period when less urgent countermeasures would be implemented to protect both individuals and the wider public from longer term, chronic risks. The boundary between the two phases cannot be defined exactly, since the circumstances and progression of a particular accident will influence when the emergency phase would be considered to be over. However, broadly, the emergency phase would constitute the time from when a release was first anticipated or occurred until it was judged that there was no further threat of release and no further need for emergency countermeasures. The recovery phase would start at the end of the emergency phase and continue until all those affected had resumed normal lifestyles.

8 The first priority of the recovery phase would be to decide whether, and, if so, what, further monitoring was required to inform subsequent decisions on the need for protective actions. These decisions would be likely to include whether and when to lift emergency countermeasures as well as the form of any subsequent recovery strategy. (Although completion of the emergency phase would mean that a satisfactory situation had been reached in terms of emergency public safety, protective measures implemented during the emergency phase might well still be in place.) The purpose of this monitoring would not only be to characterise the pattern of contamination and to quantify public exposures, but would also form the basis of estimates of likely doses to workers involved in carrying out any recovery countermeasures, or in handling contaminated wastes. In this context, the Board has advised[1] that workers in the recovery phase should be subject to the full system of radiological protection for practices as recommended by the International Commission on Radiological Protection (ICRP).

9 Clearly, all radiological protection countermeasures should have the aim of avoiding or averting exposure to radiation. However, in the context of the recovery phase, there is a second, equally important aim. The countermeasures are called recovery countermeasures because they would be implemented in order to bring the situation back to 'normal'. It might not be possible, as discussed in paragraphs 11 and 12, to reinstate exactly the pre-accident conditions. However, it is important that any countermeasures taken should assist members of the affected population, as much as possible, to return to a way of living in which the accident was no longer dominant in their thinking. Countermeasures which would prolong the uncertainty and/or disruption in people's lives (eg countermeasures continuing for years) should only be considered if the anticipated exposure levels were high, and less disruptive options could not achieve an acceptable dose reduction. For small releases, a positive decision to take no further action,

following appropriate monitoring and consultation, might actually constitute the optimum recovery strategy. The manner and context in which a countermeasures strategy was implemented could also strongly influence its overall effectiveness. It would probably be helpful, for example, to support a strategy with the provision of access to counselling and information, or to time the introduction of certain measures according to the wishes of those directly affected[13].

10 This dual emphasis on dose reduction and the promotion of an early return to normal living is a major distinguishing factor between the making of decisions on countermeasures during the emergency and recovery phases. In the emergency phase, the emphasis for decision making would be on whether or not to implement measures to counter an immediate risk. Other considerations would be of less importance since these countermeasures would be of limited duration and, consequently, limited cost (in the widest sense). However, in the recovery phase, issues such as the likely duration, the level of disruption, and how the proposed countermeasures would promote the return to 'normality', would become as important as the identification of those at risk. Thus the focus would widen in the recovery phase to include careful consideration of the ending of the proposed countermeasures as well as their initiation. In general, this means that a clear policy for ending the recovery countermeasures should form part of the strategy.

REINSTATEMENT OF PRE-ACCIDENT CONDITIONS

11 The most obvious way of facilitating the population's return to normal lifestyles would be the full reinstatement of pre-accident conditions. Unfortunately, where contamination was widely distributed (eg resulting from an airborne release), this would rarely be a practicable option. Gamma-emitting radionuclides can readily be detected down to extremely low levels, such that their presence can be detected even when the radiation risk they pose is negligible. Unless the contaminated area was very limited (eg that resulting from a broken sealed source), removal of all detectable contamination would probably have very damaging environmental consequences, ie the removal of all plants, trees, topsoil, buildings and hard surfaces. It is therefore important to recognise that full reinstatement of pre-accident radiation levels might have very great social and environmental costs (not to mention the significant monetary costs and the practical problems posed by the need to dispose of large quantities of resultant waste, likely to be classified as radioactive). In other words, full reinstatement of pre-accident conditions, following a release of particulate radionuclides to atmosphere, would, at best, probably be very difficult.

12 In determining a strategy for the recovery phase, it is therefore essential to develop goals for intervention which are practicable and which strike a reasonable balance between the desire for the maximum reduction of doses and the need to keep all the adverse consequences of intervention to a minimum. In particular, it might be necessary for members of the affected population to resume their normal lives in a measureably contaminated environment (albeit at a low level and with low risk). A recovery strategy would probably be more effective, therefore, if it was developed in consultation with the affected population.

RECOVERY COUNTERMEASURES

13 Much experience has been gained, particularly following the accident at the Chernobyl nuclear plant, on the prediction of doses arising from environmental contamination, on the clean-up of contaminated land and buildings, and on the wider social consequences of recovery countermeasures. Information on the likely effectiveness of decontamination techniques (in terms of the resulting factor decrease in dose rate or total dose received, hereafter termed 'dose-effectiveness') has been summarised in a recent review commissioned by the Department of the Environment[14]. This review also summarises other consequences, such as monetary costs and volume of waste arising from the techniques. In parallel, the Board has investigated recovery countermeasures more generally, in terms of the wider costs and benefits of their introduction[7]. There are two main approaches to dose reduction (other than countermeasures relating to food) that can be employed in the recovery phase: decontamination and restriction of access. Of course, an operational strategy may combine elements of both of these, but here it is helpful to discuss them separately. A more detailed discussion of the possible consequences and likely dose-effectiveness of these countermeasures is given in the appendix.

Decontamination measures

14 Decontamination techniques reduce exposure by treating contaminated areas directly. Such techniques include removing contaminated materials from the area (eg removal of soil or road planing), and redistributing or fixing radionuclides so that they are less available to contribute to exposure (eg covering contaminated surfaces to reduce direct irradiation or applying treatments to prevent resuspension and subsequent inhalation of the radionuclides). Removal of contaminated soils or surfaces reduces the exposure of those living in a contaminated area, but results in contaminated waste for which an appropriate disposal route has to be found. Redistribution or fixing of the contamination avoids waste disposal problems, but leaves the contamination *in situ*, as a quantifiable long-term risk. (Chemical fixing to reduce uptake by plants is not considered under this heading, as it is more suited to protection against the food consumption pathway.)

Restricted access measures

15 Restricted access measures reduce exposures by removing people from areas of contamination, or by controlling the time spent in such areas. Such measures may range from preventing or limiting access to localised contaminated areas (eg the site of the accident or recognised hot spots), to relocation of the resident population from, and prohibition of all access to, an area for weeks, months or even years until general exposure levels have reduced to acceptable levels.

Effectiveness of countermeasures

16 The implementation of these two types of interventions can result in a wide range of levels of dose-effectiveness, disruption and cost, as discussed in the appendix. Simple decontamination measures, such as hosing streets or cutting grass, can, in general, be undertaken at relatively low cost and with very little disruption to the population, and may provide a moderate reduction in dose. Similarly, prohibiting or reducing access to certain communal or semi-natural areas may be achieved with limited adverse consequences. At the other end of the scale, highly invasive decontamination techniques, such as the

widespread removal of soil or building surfaces, and the relocation of people away from their homes and workplaces for protracted periods, are likely to be very costly and disruptive, although they would also be expected to reduce doses very substantially, if not completely.

17 The timescale and level of disruption resulting from recovery countermeasures and the scale of resources required to implement them would be strongly dependent upon the size and nature of the areas contaminated. Although general guidance can be given on the likely impact and resource requirements of different countermeasures, it should be recognised that there may well be circumstances for which a very different evaluation would be appropriate. For example, permanent relocation to nearby locations, carried out for a few isolated households, may prove to be relatively undisruptive and require relatively few resources, while the implementation of grass cutting to include all private gardens in a large town is likely to require a major resource commitment and, because of the prolonged time taken, may even prove quite disruptive. It is therefore difficult to be prescriptive when providing generalised advice on the merits of implementing different recovery countermeasures. However, it is possible to divide potential recovery countermeasures broadly into three categories: those that are moderately dose-effective, incur relatively little disruption or require few resources, and which can be completed soon after the accident (Category A); those that are more strongly dose-effective, but which incur significant disruption and/or require significant resources, or can only be carried out over protracted periods (Category B); those that are either poorly dose-effective, or are only moderately dose-effective and incur significant disruption and/or require significant resources (Category C). Examples of these are given in Table 1, and an expanded discussion of them is given in the appendix.

18 Clearly, it is not useful, from a radiological protection viewpoint, to consider implementation of recovery countermeasures from Category C: either these measures achieve a small dose reduction or other countermeasures could be implemented which would achieve the same or a better reduction in dose for less disruption or cost. However, it is recognised that consideration might be given to countermeasures from this category,

TABLE 1 *Recovery countermeasures categories**

Category	Description	Likely example
A	Moderately dose-effective, relatively low disruption/ resource requirement, prompt implementation, completed within about a month	Ploughing large areas of grass Extended evacuation/short-term relocation (short-lived radionuclides) Vacuum sweeping/firehosing all metalled surfaces Grass cutting
B	Dose-effective, relatively high disruption/resource requirement, long duration/ lasting impact	Turf/soil removal and replacement Double digging all soil/grass areas Road planing Prolonged or permanent relocation
C†	Either: poorly dose-effective Or: moderately dose-effective, but high disruption/resource requirement etc.	Firehosing buildings Sandblasting walls Roof replacement Cleaning indoor surfaces

* For more information on the likely dose-effectiveness of these countermeasures, see the appendix.

† Although these countermeasures are unlikely to be justified on radiological protection grounds alone, they may be included within a recovery strategy because of other anticipated benefits (such as the reassurance provided).

in combination with countermeasures from Categories A and B, for reasons other than radiological protection. A particular example is the cleaning of indoor surfaces. This countermeasure would not normally be expected to avert much dose[14], but might well provide a high degree of reassurance for some people.

Timing of countermeasures

19 A number of often competing factors could affect the time at which it would be optimum to start to implement a particular recovery countermeasure. Some decontamination measures would need to be implemented promptly in order to be dose-effective, and social factors would also, in general, indicate a need for starting recovery countermeasures as soon as possible after the emergency phase. However, in order to plan the practical implementation of countermeasures, particularly those involving major resources or disruption, it would be necessary to undertake detailed monitoring to obtain a thorough understanding of the distribution of contamination. Without this, resources might not be optimally targeted and it would be difficult to ensure that the doses received by those carrying out the recovery countermeasures were as low as reasonably achievable. Clearly, such detailed monitoring and planning would necessitate a delay in the introduction of the measures. Although such a delay might not have major implications for the overall level of protection achieved in terms of averted dose (particularly for releases dominated by long-lived radioisotopes), the possibility of increased anxiety within the affected population and consequent breakdown in trust between this population and those responsible for managing the post-accident situation would need to be addressed. It is important that any proposed framework for developing decisions during the recovery phase takes account of such competing needs.

PRINCIPLES FOR INTERVENTION

20 The Board has published principles for intervention which should underlie the derivation of intervention levels used in accident response planning in the UK[1]. These are consistent with those recommended by ICRP[5], that countermeasures should produce more good than harm (be 'justified') and be introduced in a manner that maximises the benefit achieved (be 'optimised'). In this context 'good', 'harm' and 'benefit' are to be interpreted in the widest sense, including such factors as disruption, monetary cost and reassurance, as well as dose considerations. There is also a third principle, that every effort should be made to avoid individuals receiving doses that might cause serious deterministic injuries*.

21 The Board's first two principles require that an assessment should be made of all the harms and benefits that are likely to result from an intervention, and that an appropriate balance be struck between them. In the case of recovery phase interventions it is likely that the social costs of disruption (for those affected by the measures) and continuing long-term anxiety about residual levels of contamination (for those continuing to live in the area) would be important factors. Where the intervention would close places of employment, or involve significant periods of relocation, the long-term monetary costs could also be very high. The need for reassurance and security in people's lives would also need to be recognised as an important factor in the optimisation process. For example,

* The Board's advice on the thresholds for serious deterministic injuries can be found elsewhere[15].

decontamination measures carried out over a very long period, or restricted access to certain areas for many years, could form a persistent constraint on individual lifestyles and reinforce perceptions of the *abnormality* of the situation. Or again, it might be safe for a relocated population to return to an area several years after an accident, but many people might prefer to remain within their new communities and working environments. It would therefore be necessary to evaluate the likely duration of proposed interventions and any continuing disruption and to include this assessment in the decision making process.

Dose limits and other chronic exposure criteria

22 In setting appropriate radiological protection criteria, it is important to recognise that, in general, these do not represent the boundary between what is 'safe' and what is 'unsafe'. Such criteria represent what is considered an acceptable balance between the possible harms and benefits of an action. In particular, annual dose limits for workers and the public represent the highest level of exposure at which the benefits of undertaking a practice can be judged to offset the additional health risks incurred by those exposed. Since this balance was developed specifically in relation to practices, there is no *a priori* reason why it should represent an appropriate balance for intervention after accidents. In fact, because in many postulated post-accident situations the harmful consequences of intervention to reduce doses (in terms of disruption and cost to society) could be significantly higher than those that would result from reducing public exposures from practices, it is reasonable that this balance should result in somewhat higher (less restrictive) dose criteria for intervention than for practices. For this reason the Board advises that the annual limit on effective dose for members of the public does not apply directly to intervention after an accident.

23 Although it is clear that the balance of harms and benefits differs between practices and intervention, one aim of recovery countermeasures is to facilitate a return to normal living. Where long-lived radionuclides were involved, the potential for exposures to continue for many years in the future would conflict with the need for the population to resume a normal lifestyle. Inevitably, in these circumstances, while annual dose limits would clearly not be directly applicable, parallels would be drawn with criteria for chronic

TABLE 2 *Dose criteria and levels for protracted exposures*

	Criterion/level
Routine operations[16,17]	
ICRP/NRPB recommended dose limit for the public	$1\ mSv\ y^{-1}$
ICRP/NRPB recommended dose limit for workers	$20\ mSv\ y^{-1}$
NRPB recommended maximum dose constraint*	$0.3\ mSv\ y^{-1}$
Long-term continuing contamination (NRPB advice)	
Land not currently available for unrestricted use[18]	$0.3\ mSv\ y^{-1}$
Land currently in public domain[18]	1 Sv lifetime†
Intervention against radon in dwellings[19]	Approx. $10\ mSv\ y^{-1}$
Natural exposures[20]	
UK average from all natural sources	$2.2\ mSv\ y^{-1}$ (100–200 mSv lifetime)
Range of individual UK doses from natural sources	$1-100\ mSv\ y^{-1}$

* This applies to the dose from a single source.

† Where land currently in the public domain is discovered to be contaminated, the situation has parallels with the recovery phase after an accident, and many of the considerations discussed in this advice apply. The 1 Sv lifetime dose criterion forms an overall constraint on the optimisation of intervention.

exposure situations, both intervention and routine. Criteria for recovery intervention after accidents must, therefore, be set in the context of these other dose criteria, while at the same time reflecting the specific needs of the post-accident situation. For ease of reference, relevant dose criteria for protracted exposures are summarised in Table 2, together with typical exposures to natural radiation.

International advice

24 ICRP, the International Atomic Energy Agency (IAEA) and a Working Group set up under Article 31 of the Euratom Treaty have all published advice on relocation[5,21,22]. However, little formal guidance has been published on other restricted access measures or on decontamination measures. The international bodies recommend that if lifetime doses are projected to exceed 1 Sv, or dose rates are likely to exceed approximately 10 mSv per month, then relocation will almost certainly be justified. In some circumstances, adoption of the latter criterion could imply appreciable individual exposures. The international bodies therefore also recommend that, once an accident has occurred, it should be considered whether circumstances permit intervention at lower levels and decontamination of the affected areas.

RECOMMENDED RECOVERY INTERVENTION CRITERIA

25 In the following paragraphs, except where stated otherwise, the dose referred to is the sum of the effective dose from external radiation and the committed effective doses from inhalation of resuspended radionuclides and from inadvertent ingestion resulting from contact with contaminated materials. It is also the projected dose, ie it excludes all doses committed during, or arising from, the emergency phase. Although the doses received during the emergency phase are relevant for informing decisions on recovery countermeasures, they cannot be affected (averted) by such countermeasures. They, therefore, should be considered separately from the avertable doses within the process of balancing the possible harms and benefits of different proposed strategies.

26 Ideally, when assessing projected doses, best estimates of the doses that individuals would receive in the course of their normal living should be obtained. However, in undertaking the assessments, two points should be recognised. First, the acceptability of the proposed intervention should not be dependent upon the specific lifestyles of particular individuals: the intervention should be acceptable for any individual or family moving into the area in the future having a lifestyle that is within accepted social norms. Second, there will be competing pressures between the need to make prompt decisions and the need to inform such decisions adequately. The level of resource allocated to the determination of projected dose estimates should reflect the relative importance of these competing pressures. Where the need for prompt decisions is paramount, then a simple screening (over)estimate could be made, by assessing the sum of the external and inhalation doses to a child assumed to reside permanently outdoors.

International recommendations

27 It is considered that the criteria recommended by ICRP, IAEA and the Article 31 Working Group for relocation are appropriate for application in the UK, in the following context. The 10 mSv per month criterion for relocation is appropriate as an upper bound for determining the need for relocation, and, in practice, is likely to be most useful in the

context of contamination dominated by radionuclides with halflives of the order of days, such as iodine-131. The 1 Sv lifetime effective dose criterion is appropriate as an upper bound applicable to all forms of recovery countermeasures. In recommending this lifetime criterion, the intent is to limit the extent to which an individual may be disadvantaged, in terms of radiation risk, by the accident (ie to limit inequity). Therefore it is advised that the criterion should apply to the sum of doses received and/or committed during both the emergency and recovery phases, as a result of the accident.

28 In view of the potential large-scale disruption and costs associated with many types of decontamination and restricted access measures, it is helpful to provide additional guidance on when different levels of intervention would be likely to be optimum. Clearly the range of specific countermeasures that could be considered in a real event would be constrained by the scale of the contamination and the circumstances of the accident. However, it is useful to divide recovery countermeasures into three categories, according to the level of resource requirement/disruption involved and the dose-effectiveness likely to be achieved, as indicated in Table 1. It is recognised that the actual consequences resulting from different countermeasures would be strongly dependent upon the nature and location of the accident and the weather conditions at the time. For this reason, the examples given in the table are provided for broad guidance only: specific circumstances may cause some of the listed Category A countermeasures to be considered Category B, and vice versa.

Recovery countermeasures

Category A

29 Measures in Category A would generally be completed within the first month following the end of the release, and once completed, would incur no further disruption to the lives of those living in the area. Since the costs (in the widest sense of the word) of such countermeasures would be relatively small, these countermeasures could be implemented fairly promptly, without the need for detailed monitoring and careful targeting. Prolonging evacuation by a few days, cutting grass or firehosing hard surfaces are examples of recovery measures likely to be appropriate for this category. In a wide range of situations, such measures would meet the aim of facilitating a prompt return to normal living. In the right circumstances, combinations of such measures can also be highly dose-effective. For this reason, it is recommended that consideration always be given to whether it would be appropriate (ie both justified and optimised) to carry out recovery measures in this category following any accidental release with the potential to expose the public after the emergency phase. Whether or not any recovery countermeasures were justified after a specific accident would clearly depend upon the particular circumstances of that accident. However, the prompt implementation of appropriate combinations of such countermeasures should ensure that doses were reduced to low levels (eg at most a few millisieverts in the first year following the accident) after all but the most severe accidents.

30 In this context it is important to recognise that while the need or otherwise for emergency countermeasures would be a relevant factor contributing to decisions on the need for recovery countermeasures, it probably would not be the determining one. In other words, accident scenarios can be envisaged for which emergency countermeasures alone, or recovery countermeasures alone, would be implemented. For example, emergency countermeasures might be implemented in response to a release of noble

gases, or precautionary emergency countermeasures might be implemented in response to a threatened release, which, in the event, did not actually occur. Although for both these scenarios appropriate monitoring might be carried out in order to demonstrate that no further action was required, there would be no reason to initiate recovery countermeasures. Conversely, a low level or sudden release either might not merit emergency countermeasures, or might be over before emergency countermeasures could be carried out. However, there could subsequently be a need for the implementation of recovery countermeasures.

Category B

31 Recovery measures in Category B are more strongly dose-effective measures which would be difficult to complete within the first month following cessation of the release(s), or which would continue to cause disruption after they were completed, or which would require very substantial resources. Since the costs (in the widest sense, and including the likely exposure of workers involved in implementing the countermeasures) could be very large, it would generally be necessary to plan and target the implementation of these countermeasures carefully. It is therefore unlikely that countermeasures from this category would be implemented as promptly as those in Category A. Recovery measures in this category would generally include road planing, removal of topsoil, prolonged restricted access and prolonged relocation. Such measures would not facilitate a prompt return to normal living, and so, to offset this, the risk reduction achieved by such measures should be significant. It is judged that measures in this category would be most unlikely to be justified in circumstances where the annual projected dose to exposed individuals was less than 10 mSv. At projected doses of around 10 mSv in the first year, it is likely that only the least disruptive of this category of measures would be justified. In general also, such measures would be targeted at vulnerable groups (ie those at relatively higher risk) and limited areas. For higher projected doses, or for situations where the exposure was projected to continue at similar levels over a number of years, consideration would need to be given to increasingly disruptive and costly measures, including relocation.

32 In determining the strategy that offered the best overall balance between the resulting harms and benefits, the aim of facilitating a return to normal living would make it particularly important to identify all the factors and issues that were relevant. These would involve factors of context, such as doses received during the emergency phase and general social and environmental issues, as well as the scale of the direct consequences (eg dose averted, monetary cost and disruption) of the proposed strategy. Where large populations were involved, an estimate of the collective averted dose might also be relevant, as one measure of the possible health benefit to society of a proposed action. The potential benefits of a combined strategy of two or more recovery measures (including countermeasures aimed at addressing social, as opposed to radiological, consequences of the accident) should also be considered, particularly if such a combined strategy could reduce the level or duration of disruption and increased anxiety.

33 It must also be recognised that, following an accident in which widespread contamination of the environment occurred, it might be neither reasonable nor practicable to decontaminate an area so as to reduce exposure levels to those that pertained before the accident. In other words, it should be recognised that 'normal' lifestyles might have to be resumed in the context of higher exposures to radiation than

were considered acceptable before the accident. However, any acceptance of such higher levels should take place in the context of a careful and explicit balancing of the harms and benefits of different possible recovery strategies, in a process that involved both those affected by and those with responsibility for the decision and its implementation. Such decisions should also be constrained by the 1 Sv individual lifetime dose criterion for doses resulting from the accident, and by the need to prevent individual exposures exceeding the thresholds for serious deterministic injuries.

Category C

34 Measures in Category C would not in general be justified on radiological protection grounds. However, they might be included in a recovery strategy, either because the circumstances of the accident prevented other, less resource-intensive countermeasures being implemented, or for reasons other than dose reduction. They are most likely to be used in support of a wider recovery strategy involving countermeasures from one or both of the other, more dose-effective, categories.

SUMMARY

35 The purpose of this advice is to provide a framework for decisions on recovery countermeasures in the UK. Such decisions should take account both of the expected radiological benefit of the countermeasure and of its likely contribution to promoting an early return to normal living within the affected population. Important factors therefore include the likely scale, duration and resource requirements of a countermeasure. Where these are large, the Board recommends that they should be offset by a correspondingly significant level of anticipated averted dose (ie at least 10 mSv in the first year). Less disruptive or resource-intensive measures could be considered for averting lower levels of dose. In fact, the Board recognises that there may be (non-radiological) grounds for implementing some simple countermeasures even where the anticipated averted dose is very low. Table 1 presents a generic division of recovery countermeasures into three categories according to the likely levels of averted dose, resource requirements and disruption involved. This division will not be appropriate for all possible post-accident circumstances, but is provided to illustrate the intended application of the Board's advice and to provide a starting point for the development of a recovery strategy.

36 Although the development of an optimum recovery strategy should include appropriate consideration of potential inequities, it is important to specify a limiting dose criterion as a safeguard for individuals. In accordance with international

TABLE 3 *Summary of advice on recovery countermeasures*

	Countermeasures	
Circumstance	To consider	Unlikely to be justified
Any offsite contamination	Category A	Category B, Category C*
Dose > 10 mSv y^{-1}	Category A, Category B†	Category C‡
Lifetime dose > 1 Sv	All	None

* May be justified in support of other measures.

† Need to offset increasing resource requirements/disruption with increasing dose averted; in general, relocation would not be justified at doses around 10 mSv y^{-1}.

‡ May be justified in support of other measures, or if Category B measures impractical.

recommendations, the Board advises that every effort should be made to ensure that no individual receives a total dose from an accident exceeding 1 Sv.

37 The Board's advice is summarised in Table 3.

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Appendix

EFFECTIVENESS OF RECOVERY COUNTERMEASURES

Introduction

The Board's advice on recovery countermeasures recognised three categories of measures: those that are moderately dose-effective, incur relatively little disruption or require few resources, and which can be completed soon after the accident (Category A); those that are more strongly dose-effective, but which incur significant disruption and/or require significant resources, or can only be carried out over protracted periods (Category B); those that are either poorly dose-effective or are only moderately dose-effective and incur significant disruption and/or resources (Category C). Examples of countermeasures likely to fall into each of these categories are listed in the table. In this appendix, the likely costs and benefits of a range of countermeasures that might be considered for the recovery phase are discussed. This discussion is in general terms only: the specific consequences of applying different countermeasures will, of course, depend both upon the circumstances of a particular accident and upon the overall recovery strategy adopted (ie the interaction between different individual measures). A more detailed discussion of the decontamination measures can be found elsewhere[1].

Decontamination measures

The relative effect of decontaminating a particular surface on the dose received by an individual is dependent upon the contribution of that surface to the individual's total dose and the success of the decontamination. The importance of a surface in contributing to dose depends upon a number of factors. These include the relative deposition on to different surfaces, how fast activity weathers off the surface, where it is redistributed and where people spend their time.

The importance of each surface in contributing to dose is also dependent upon whether the initial deposition was wet or dry. However, it has been shown that, in either case, exposure from outdoor ground surfaces dominates the total dose at all times. Soil and grass contribute the majority of the dose when the deposition occurs under dry conditions, while metalled surfaces also make an important contribution for wet deposition. It is therefore clear that the largest dose reductions will be achieved by recovery countermeasures which either decontaminate or restrict access to soil, grass and metalled surfaces. Decontamination of, or prohibiting access to, buildings is unlikely to result in significant reductions in dose. Generally, countermeasures implemented with respect to individual surfaces are considerably less effective for wet deposition compared with dry deposition, with the exception of metalled surfaces where the reverse is true (because these surfaces collect some runoff from other surfaces).

Vacuum sweeping and firehosing metalled surfaces are among the lowest cost decontamination measures. They also have the advantage that they could be carried out relatively quickly, with little subsequent disruption to the population. As noted above, these techniques are likely to provide the greatest reduction in dose for deposition occurring under wet conditions, but since they do not affect deposition on grass and soil surfaces, they can only, at best, be moderately dose-effective.

Dose-effectiveness of recovery countermeasures

Category*	Technique	Likely dose-effectiveness†
Category A		
Moderately dose-effective;	Ploughing of large areas of grass – eg playing fields, parks	M
low disruption/resource requirement;	Extended evacuation – short-lived radionuclides	M
can be completed within a month	Vacuum sweeping – all metalled surfaces	M
(with minimal continuing disruption	Firehosing – all metalled surfaces	M
after this time)	Grass cutting and removal – public and private areas	M
	Temporary relocation for one month	H/M/L‡
Category B		
Highly dose-effective;	Turf removal and replacement – public and private areas	H
high disruption/resource requirement;	Rotovating all soil/grass areas	H
timescale of months to years for	(assumes all shrubs and plants removed and replaced)	
completion (including cessation of	Double digging all soil/grass areas	H
disruption)	(assumes all shrubs and plants removed and replaced)	
	Turf and soil removal and replacement – all soil/grass areas	H
	(assumes all shrubs and plants removed and replaced)	
	Road planing and replacement	H/M§
	Prolonged or permanent relocation	H
Category C		
Poorly to moderately dose-effective;	Firehosing buildings	L
moderate–high disruption/resource	Sandblasting walls	L
requirement	Tree felling/plant and shrub removal and replacement	M
	Strippable coating – metalled surfaces and buildings	L
	Ammonium treatment of buildings	L
	Roof replacement	L
	Cleaning of indoor surfaces	L

* This grouping into categories is inevitably very broad; the actual dose-effectiveness, disruption and resource requirements of the countermeasures would be highly dependent upon the exact circumstances of the accident and its aftermath – see detailed comments in text.

† Dose-effectiveness is defined in this table as the reduction in the overall external exposure from deposited gamma-emitting material from all surfaces in an urban environment:
H high dose-effectiveness (30–60%)
M moderate dose-effectiveness (20–40%)
L low dose-effectiveness (<10%)
A discussion of the dose-effectiveness of decontamination techniques for alpha-emitting radionuclides is given in NRPB-R288[1].

‡ Dose-effectiveness is very dependent upon the effective halflives of the radionuclides involved; for radionuclides with a halflife of a few days (eg iodine-131) relocation for one month would be very highly dose-effective (ie approaching 100%).

§ High dose-effectiveness is possible for deposition in wet conditions only, since relatively more dose arises from other surfaces following dry deposition.

Grass cutting and collection are most effective following deposition under dry conditions as a larger fraction of the deposited activity is intercepted by the grass. The effectiveness of this technique will depend upon the length of the grass at the time of deposition, being less effective for recently mown grass, and on its implementation before substantial rainfall. The cost of this countermeasure would depend upon the relative areas of gardens to large grassy areas such as playing fields, but would generally be of an intermediate level of cost in the context of the recovery countermeasures listed in the table. The great advantage of this recovery countermeasure is its dose-effectiveness coupled with low disruption; once carried out, although there are obvious practical problems associated with disposal of the grass cuttings, there is no further disruption for those living in the contaminated area.

Soil removal, ploughing, rotovating and digging lead to relatively large dose reductions, around 40–60%. The choice of measure would depend upon the size of the individual areas affected. Ploughing and removing soil/turf from large open spaces and verges will lead to low disruption and, as large machinery can be used, the monetary costs are kept relatively low compared to the clean-up costs of private gardens. Measures applied to private gardens, such as digging and soil/turf removal, are labour intensive and hence expensive and could lead to prolonged disruption of the local community. Any measure that removes soil/turf gives rise to large volumes of organic waste and significant associated disposal problems.

Tree felling/shrub removal can lead to some reduction in dose in the first year, following dry deposition, but is generally only potentially worthwhile in certain specific situations, ie where deposition has occurred in spring or summer under dry conditions and where there is a high density of trees and shrubs around buildings. Such measures, however, are likely to have a prolonged disruptive influence on the local community, since it may be many years before newly planted shrubs and trees regain the appearance of mature surroundings. They can also be fairly costly and resource-intensive to implement.

The planing of metalled surfaces, coupled with subsequent resurfacing, can be very effective in reducing exposure from these surfaces, although the degree of dose-effectiveness is partly dependent upon the smoothness of the surface, and problems can occur in decontamination around drains and gutters. However, this technique is both costly and disruptive, and would create large volumes of contaminated waste for disposal. Since resurfacing will effectively fix any remaining activity and prevent natural weathering of it, and will provide only limited shielding, the addition of asphalt or tarmac as a covering for contaminated metalled surfaces without prior planing is unlikely to achieve much reduction in dose.

Combinations of techniques can be implemented to form a countermeasures strategy. For example, firehosing of metalled surfaces combined with grass cutting and removal are likely to be particularly effective, while incurring only relatively low disruption and requiring relatively small resources.

Restricted access measures

The dose-effectiveness of restricted access measures will depend upon both the potential exposure rate and the length of time individuals would spend in an area if restrictions were not imposed. Except in very specific circumstances, eg contamination within a building resulting from a damaged sealed source, as occurred at Goiânia[2], the inside surfaces of buildings are unlikely to become significantly contaminated. For accidental

releases to air or water, therefore, restricting access to buildings, even those frequently used or lived in, would be unlikely to achieve significant reductions in overall exposures. However, restricting access to frequently used outdoor areas where relatively high deposition had occurred could provide a substantial reduction in dose.

Exposure from short-lived radionuclides can be avoided almost completely by prohibiting access to the contaminated area for a few days or weeks. Where the contamination is very localised, people can continue to live in its proximity, but the problem area itself can be 'fenced off'. Where the contamination is more widely dispersed, it may be necessary to relocate a population group away from the area until the radionuclides have decayed. Although short-term relocation or restricting access to limited areas for a few weeks may be disruptive while in force, such restrictions are clearly temporary and have a well-defined endpoint. Once the appropriate period has elapsed, the environment will be essentially 'clean' and normal lifestyles can resume. Thus, for protection against short-lived radionuclides, restricted access measures have the potential to provide high dose-effectiveness for relatively small social cost.

For protection against radionuclides with halflives of months or years, restricted access measures would need to be correspondingly prolonged. If the restricted areas would normally have been frequently used, then the disruption experienced by individuals, the relative dose-effectiveness of the measure and the monetary costs involved would all probably be high. This is, of course, particularly true in the case of long-term or permanent relocation. In contrast, restricting access to an area not normally used by the public might engender a high degree of reassurance, coupled with very limited disruption and monetary cost, but might avert little dose. Prolonged restricted access measures can also provide a continuing reminder and focus for resentment and anxiety over the consequences of the accident. In general, therefore, if such measures are to be dose-effective, they are also likely to incur a high degree of social and monetary cost. In such circumstances, it is likely they will only be justified where they can avert a relatively high dose (ie the potential exposure is high), and where other less disruptive and costly measures cannot provide a substantial reduction in dose.

With respect to relocation, it is important to recognise the need that people have for stability in their lives. There is therefore a limit to the period of any temporary relocation that would normally be tolerated. IAEA recommends that if relocation would be required for a period of more than one to two years, it should be treated as permanent[3]. This recommendation is endorsed here, for the UK. This does not preclude re-population of the affected area once exposure rates have reduced to levels considered acceptable, but recognises that those who settle there may well be different from the original population.

Protection of workers

The Board's principles for intervention[4] require that workers involved in recovery countermeasures should be subject to the full ICRP system of radiological protection for practices. Some of the countermeasures discussed in this appendix have the potential to expose workers to significant doses. Therefore, in determining an appropriate recovery strategy, and, more particularly, in planning its implementation in detail, assessments should be made of likely doses to workers (both for those directly implementing the measures and for those involved in handling any subsequent wastes), and steps taken to ensure that these are maintained as low as reasonably achievable (and certainly within the worker dose limits).

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APPLICATION OF EMERGENCY REFERENCE LEVELS OF DOSE IN EMERGENCY PLANNING AND RESPONSE

ABSTRACT

The Board published formal advice on emergency reference levels (ERLs) of dose in 1990. This document provides more detailed guidance on how it is intended that the ERLs should be applied in the development of emergency plans. In particular, specific guidance is developed in the following areas: how to incorporate the concept of averted dose in emergency plans; the choice of dose quantities to be compared with the ERLs; the use of ERLs in the event of an actual accident.

In order to develop the role and application of the ERLs, the different types of accident response criteria are discussed. In particular, a distinction is drawn between intervention levels (usually expressed as dose averted) and action levels (often directly measureable quantities), and also between generic and site specific accident response criteria. The ERLs are identified as generic intervention levels and, as such, their primary role is for use during the development of emergency plans. If an accident occurs, it is recommended that any urgent response should be triggered by the site specific action levels specified in the emergency plan. Subsequently, ERLs may be used to determine whether major modifications to this response are necessary. Only in the unlikely situation of the occurrence of a serious accident, for which there was no emergency plan which could be activated, should the ERLs be used as direct criteria, and then only for determining the most urgent response.

PREPARED BY M MORREY

INTRODUCTION

1 The Board has a statutory duty to provide emergency reference levels (ERLs) of dose for use in the protection of the public following radiological accidents. Formal Board advice on principles for intervention after an accident and on ERLs was issued in 1990[1,2]. The advice on ERLs includes the specification of numerical intervention levels for the urgent countermeasures of evacuation, sheltering and the administration of stable iodine, and guidance on their application in emergency planning[2].

2 Since publication of the advice on ERLs, the Board has received many requests for more detailed guidance on how it is intended that ERLs should be applied in the development of emergency plans. In particular, specific guidance has been sought on how to incorporate the concept of averted dose in a plan which is intended to facilitate a fast response, and on when single organ ERLs should be used instead of whole body ERLs. The purpose of this document is to provide additional guidance on the nature of ERLs and to suggest methods for using ERLs, both in the development of an emergency plan and in response to an actual accident.

3 This document considers only those aspects of emergency plans which are related to ERLs. It therefore only addresses the protection of members of the public. Advice on the protection of workers during and after an accident is given elsewhere[1]. It is recognised that much of an emergency plan is properly concerned with operational and organisational arrangements and lines of communication. These are important issues, but beyond the scope of this guidance. Furthermore, the approval of emergency plans is a matter for the regulator. Therefore the methods suggested here for applying ERLs in the development and implementation of emergency plans are intended for guidance only.

4 This document is divided into three main sections. The first elaborates formal Board advice on intervention and ERLs. The second and third suggest methods for applying this advice to the development of emergency plans and to the response to an accident, respectively.

GENERAL PRINCIPLES

Intervention criteria

5 Intervention criteria are numerical quantities which are used as a basis for making decisions on countermeasures. It is useful to distinguish between intervention levels (ILs) and action levels (ALs). The ILs are levels of avertable dose sufficient to justify a particular countermeasure. The ALs are levels of dose (received or projected) or directly measureable quantities (eg dose rate or activity concentration) above which action should be taken.

6 The ERLs are one type of IL, specified (only) by the Board. They are specified in terms of dose averted and apply to emergency countermeasures. The ERLs and ILs are generic quantities intended for providing broad guidance on intervention decisions. They provide a common basis between accidents and sites, which is important if public protection is to achieve a common standard. In general, it is not intended that the ERLs should be applied directly to determine the optimum urgent response to an actual accident. Rather, they should be used in the development of emergency plans[2] and, after initiation of the emergency plan in response to an actual accident, as a measure against which to check on the broad adequacy of the countermeasures being implemented.

7 The ALs can be generic or site specific. As with ILs, generic ALs are intended to be used in the development of emergency plans. Site specific ALs are used directly in emergency plans, and may be expressed as any quantity which is directly measureable or observable. They take account of the ERLs and of site and plant specific factors, and act as triggers to initiate part or all of the emergency plan. Site specific ALs may be unique to a single site, or common between a group of sites with similar plant. The gross air concentration level of 10^5 Bq m^{-3} used in a number of emergency plans to trigger advice on the need for evacuation[3] is an example of a site specific AL.

8 After an accident has occurred it may be useful to develop new accident specific ALs to provide support for decision making. Such ALs take account of the exact circumstances of the accident and are most likely to be developed for the longer term response: for example, the adoption of an external gamma dose rate criterion, determined from a generic dose criterion and knowledge of the radionuclide mix actually deposited on the ground.

Dose–response relationship

9 There are two key exposure bands relevant to emergency response, namely those where the doses and dose rates are sufficiently high to lead directly to serious deterministic injuries*, and those (lower) exposures where serious deterministic injuries will not result, but the individual will have an increased risk of developing some health problems, in particular of developing cancer. The Board has advised[1] that protective measures should always be planned to avoid exposures that might lead to serious deterministic injuries. The threshold doses for such health injuries are about 1 Gy absorbed dose to the whole body (which may result in deterministic injury to the bone marrow) and 2–3 Gy to the other most radiosensitive organs[4†]. In fact, it is most unlikely that members of the public would be exposed to such high doses and dose rates following an accidental release from a nuclear facility. For exposures in the lower band, it is generally assumed that the size of the increase in radiation risk is directly proportional to the size of the dose‡, and that there is no threshold dose below which there is no risk[5]. Within the dose range of a few millisieverts to a few hundred millisieverts, the same increment in dose gives the same increment in risk, regardless of the dose already received (eg increasing an exposure from 101 to 121 mSv gives the same *additional* risk (10^{-3} risk of fatal cancer[6]) as increasing an exposure from 1 to 21 mSv). This means that for whole body doses below about 1 Sv delivered during the first few days following an accident there is no safe/unsafe boundary of dose on which to base decisions on countermeasures. The Board therefore recommends that protective measures should be planned to reduce these exposures, provided that the benefits of the protective measures are expected to exceed the risk or harm caused by introducing them[1]. It is to exposures in this dose band that the ERLs apply.

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* Strictly, deterministic injuries or deterministic health effects are those for which the severity of the effect varies with dose and there is a threshold of dose below which the effect does not occur.

† It should be noted that skin burns from beta irradiation were implicated in the deaths of a number of emergency personnel following the accident at the Chernobyl nuclear plant. If significant beta contamination of skin is considered likely, then a separate assessment of the risk from skin exposure should be made, and countermeasures planned to avoid serious deterministic injuries from this cause.

‡ Throughout the remainder of the text, the term dose, unless otherwise qualified, is used to signify the effective dose, comprising both external exposure and the committed effective dose from intakes of radionuclides over the relevant period.

10 This absence of a safe/unsafe boundary of dose forms the basis of the principles of intervention after an accident of both the Board[1] and the International Commission on Radiological Protection (ICRP)[7]. These are that when all the consequences of taking a countermeasure have been evaluated (including socio-political as well as health and monetary factors) it should be expected to do more good than harm (ie be justified) and it should be implemented in such a way as to maximise the net benefit (ie be optimised). The Board's three principles of intervention are given in Table 1.

TABLE 1 *NRPB principles for intervention*[1]

Justification	Countermeasures should be introduced if they are expected to achieve more good than harm
Optimisation	The quantitative criteria used for the introduction and withdrawal of countermeasures should be such that the protection of the public is optimised
Avoidance of serious deterministic health effects	Serious deterministic health effects should be avoided by introducing countermeasures to keep doses to individuals below the thresholds for these effects

ERLs represent a balance

11 The Board's general principles of justification and optimisation[1] mean that a balance needs to be struck between averting radiation doses and incurring other harmful consequences. The ERLs[2] provide guidance on where this balance lies for urgent countermeasures. They indicate the level of averted dose which is likely to offset the other harmful consequences of each type of countermeasure. Since the exact consequences of a countermeasure depend very much upon the circumstances prevailing at the time and location of an accident, and because many of the consequences cannot be directly quantified, the Board specifies a range of doses, bounded by an upper and a lower ERL for each countermeasure. The lower ERL is appropriate for circumstances where the disadvantages of implementing the countermeasure are judged to be small (eg where few people would be involved, and the implementation of the countermeasure has been planned in detail in advance). The upper ERL applies to situations where the disadvantages of implementing the countermeasure are judged to be large (eg where many people would be involved, or where the implementation of the countermeasure had not been planned in advance). These upper and lower ERLs are indicative, rather than precise, values. In fact, as discussed elsewhere[2], they represent 'a few', 'a few tens' and 'a few hundreds' of millisieverts. The ERLs for the countermeasures of sheltering, evacuation and the issue of stable iodine are reproduced in Table 2.

ERLs are avertable doses, not limits

12 The Board's third principle for emergency planning and response requires that every effort be made to prevent individuals receiving doses which could cause serious deterministic injuries[1]. The advice on ERLs is specific to anticipated exposures that are less than this, ie up to about 1 Sv in a few days. The ERLs refer to the doses which are likely to be averted if the countermeasure is implemented. The ERLs are therefore not limits on the dose which may be 'safely' received by an individual, but an indication of the level of dose, expected to be averted by the countermeasure, which would justify the potential risk and disruption of taking that countermeasure. It is therefore important that countermeasures should not be introduced solely to prevent the total exposure of an

TABLE 2
Recommended ERLs for urgent countermeasures

Countermeasure	Body organ	Dose equivalent level* (mSv) Lower	Upper
Sheltering	Whole body†	3	30
	Thyroid, lung, skin‡	30	300
Evacuation	Whole body†	30	300
	Thyroid, lung, skin‡	300	3000
Administration of stable iodine	Thyroid	30	300

* These values should be interpreted as approximate figures.
† The numerical values for whole body ERLs may also be used for comparison with the quantities of effective dose and effective dose equivalent.
‡ These single organ ERLs were specified prior to the definition of effective dose by ICRP. Their use now would not normally be expected (see paragraphs 19 and 20).

individual exceeding these levels. That would only be meaningful if the ERLs indicated thresholds for serious deterministic injuries, which they do not.

13 The principle of optimisation states that countermeasures be implemented in such a way as to maximise the net benefit. The avertable doses specified by the ERLs are an indication of the level of dose saving that would just achieve a net benefit in specified circumstances; clearly a greater dose saving, if possible, would increase the net benefit. This means that, with due regard to the likely course of the accident, and the overall harms and benefits likely to be experienced by the individuals involved, countermeasures should be implemented as quickly as reasonably possible. If adequate planning cannot provide for a reasonably prompt implementation of one countermeasure, then consideration should be given to whether an alternative strategy, that can be implemented more promptly, would be more appropriate. Clearly, following an actual accident, unforeseen delays might occur. In such circumstances, it would be necessary to do the best that was reasonably practicable.

ERLs are probable doses, not certain doses

14 It is not possible, either before or during an accident, to know precisely what doses may be averted by a countermeasure. If an urgent countermeasure is delayed while sufficient information is obtained to estimate the actual avertable dose, much of the potential benefit of taking that countermeasure may have been lost. Decisions to take urgent countermeasures will be based on limited information and modelling, and so on broad, probably cautious, estimates of the doses likely to be averted. Consideration of the implications of implementing countermeasures based on incomplete information should form part of the development of an emergency plan. The Board particularly recommends that consideration be given to the use of precautionary countermeasures, ie countermeasures implemented because a serious release is expected or suspected, but before it has actually occurred or been detected[1,2].

ERLs are for children

15 It is important to recognise that no population group is homogeneous. The aim of emergency planning and the implementation of countermeasures must be to ensure the most good to the most people, not to attempt to provide uniform net benefit to everyone. For every countermeasure and population group it will always be possible to

identify individuals who gain less benefit from (or who may even be disadvantaged by) the countermeasure.

16 When calculating averted doses for comparison with the ERLs, it is inappropriate to use assumptions of extreme or very unusual behaviour. However, in the development of the ERLs it was recognised that, in general, society would give priority to the protection of children in the event of an emergency[2]. Therefore, the ERLs were developed for children and, strictly, the averted doses to be compared with them should be doses to children. In fact, the variation of dose factors with age for many of the radionuclides likely to be considered in an emergency plan is not large compared with the other uncertainties inherent in the planning. Therefore a plan based on doses to adults should not, in general, be significantly different from one based on doses to children. If the choice between adult and child doses appears significantly to change the overall emergency plan, then serious consideration should be given to whether the plan is actually robust for an appropriate range of circumstances.

Whole body ERLs may be compared with effective dose

17 Since publication of the ERLs[2] ICRP has introduced the quantity 'effective dose'[8] to replace the quantity 'effective dose equivalent'[9]. Effective dose provides a quantification of the risk in terms of fatal and non-fatal cancer and hereditary injury to all generations, whereas effective dose equivalent expresses the risk of solely fatal cancer and hereditary injury in the first two generations only.

18 In the Board's guidance on ERLs for urgent countermeasures[2] it is advised that the quantity effective dose equivalent is appropriate for comparison with the ERLs of dose to the whole body. Although, inevitably, there are differences in numerical value between effective dose equivalent and effective dose, this difference is generally small in comparison with the uncertainties inherent both in the predictions of avertable doses and in the input of subjective judgement to the specification of the ERLs themselves. It is therefore advised that both effective dose equivalent and effective dose are appropriate surrogates for whole body dose when making comparisons with the ERLs.

ERLs for organs

19 The Board has specified ERLs for three countermeasures: evacuation, sheltering and the administration of stable iodine. Since the administration of stable iodine only has the potential to reduce thyroid doses, ERLs are only specified for thyroid dose for this countermeasure. However, for the other two countermeasures ERLs are provided for specific organ doses as well as whole body doses. This discussion relates only to the application of ERLs for these two countermeasures, ie sheltering and evacuation.

20 The definitions of both effective dose equivalent and effective dose provide an adequate representation of the risk of fatal cancer, whether the exposure is to the whole body or concentrated within a single organ. Therefore, the whole body ERLs alone are a sufficient basis for protection against the risk of fatal cancer. The purpose of specifying organ ERLs for the countermeasures of sheltering and evacuation was primarily to provide advice for situations in which the risk of non-fatal cancer in a particular organ was more significant than that of fatal cancer. Since the quantity effective dose equivalent did not include consideration of the risk of non-fatal cancer it was necessary to specify separate ERLs for those organs (principally thyroid and skin) which suffer a significant risk of non-fatal cancer (relative to fatal) following exposure to radiation. If the quantity

effective dose is used for comparison with the whole body ERLs, then the risk of non-fatal cancer has already been taken into account. In this case, provided that the projected whole body and organ doses are below the thresholds for serious deterministic injuries, there is no radiological protection advantage to be gained from separately comparing organ doses with the ERLs for organs. If such a comparison shows that the organ dose is more 'limiting', then this is a consequence of the imprecision of the ERLs, not an indication of an intended difference between the two.

USE OF ERLs IN THE DEVELOPMENT OF EMERGENCY PLANS

21 Following a radiological accident, members of the public may be at risk both from relatively high doses over the first few days after the accident and from chronic doses over the subsequent weeks, months or even years. Generally, in order to be effective, countermeasures intended to provide protection against short-term intakes and exposures ('urgent' or 'emergency' countermeasures) will need to be taken very quickly. Conversely, decisions on countermeasures intended to provide protection against chronic intakes and exposures ('longer term' countermeasures) could be delayed, at least until there is no further potential for release and a reasonable number of environmental measurements have been made.

22 A well-constructed emergency plan is mainly concerned with the urgent response to an accident. Its purpose is to define the immediate response structure and arrangements for establishing control. General recommendations on the development of an emergency plan are outside the scope of this document. The following guidance relates only to the incorporation of Board advice on ERLs and intervention within the plan. The Board provides ERLs to assist in the determination of appropriate countermeasures for which to plan, and in the setting of site specific ALs. Paragraphs 23–31 discuss how the ERLs could be used to do this.

Emergency plans should be straightforward

23 In order for an emergency plan to be effective, it must be clear and straightforward to follow. Although the Board's principles for intervention state that countermeasures should be both justified and optimised, it is not intended that the need for mathematical optimisation should take priority over clear planning and, where required, rapid response. The advice to optimise response should be interpreted in the broadest sense, ie to make best use of the available information within an appropriate timescale. One way in which this can be achieved is by the development of a single, robust plan for the urgent response to most envisaged accidents and circumstances. Such a plan would clearly indicate the *few* types of accidents and circumstances for which it was inappropriate, and give alternative responses for these. It is recognised that the response dictated by such a plan would be unlikely to be precisely optimum for any specific accident. However, this disadvantage would be offset by the advantages of a speedy response facilitated by a clear and straightforward emergency plan.

Identification of accidents

24 Ideally, the development of an emergency plan would involve the identification and quantification of the range of possible accidents and circumstances that might arise, and their potential consequences[1]. It is recognised both that such an evaluation could require a

very significant input of resources and that an actual accident is unlikely to correspond exactly to any one of those considered beforehand. The objective of such studies would be to ensure a sufficient understanding of the range of potential accidents and consequences in order for there to be confidence in the emergency plan. Clearly, a balance would need to be struck between the need adequately to understand the potential for accidents at the plant and their consequences, and either wasting resources or developing a rigidity of thinking that would prevent an adequate response to an actual accident. It is also recognised that although the detailed procedure discussed below may be appropriate for plant where the accident risks are not well known, a simpler analysis based on only one or two 'reference' accidents may be more appropriate in situations where the risk and range of accidents has already been well explored, and so appropriate reference accidents can be selected. The following discussion is intended to be understood in this context.

25 In order to quantify the consequences of potential accidents, account would need to be taken of the factors most likely to influence them. Depending upon the site, the analysis might include the influence of different weather conditions and seasonal demographical factors on the impact of each type of accident. The degree of detail used in the studies would be linked to both the expected probability of each postulated scenario and the severity of its consequences, with the most unlikely or least hazardous scenarios being considered in the least detail. Based on such studies, the range of doses to the local populations which would be expected in the absence of countermeasures could be estimated. These doses would normally be best estimate values of child doses, taking into account, to the degree appropriate, such factors as the likely shielding provided by buildings (for the sheltering countermeasure) and the normal activities carried out in the area. The likely dose savings which could be achieved by implementing a range of countermeasures, both singly and in combination, could then be estimated, again as realistically as appropriate, given the likely probability and consequences of the accident, and the degree of detail appropriate to the overall study. From these assessments the doses potentially received at different times after the accident and different distances from the site, together with factors for possible dose savings, could be estimated.

26 It seems reasonable that such assessments would take account of the likely delays in the initiation of the countermeasures and the time it would take to implement them. If the studies indicated that the envisaged implementation times significantly reduced the possible dose savings which could be achieved, then serious consideration should be given to how these implementation times could be shortened, so as to increase the net benefit from the countermeasure.

Identification of appropriate countermeasures

27 For each accident scenario investigated the potential dose savings to children from the implementation of each countermeasure could be compared with the appropriate ERLs. Again, it is reasonable that the level of detail of this comparison would be linked to the probability of the accident and the scale of the consequences. It is likely that the potential dose savings would vary geographically, depending upon many factors, including the total potential dose at a location, the time available for implementing countermeasures before most of the dose would be received, and the time it would take to implement countermeasures in particular locations. In general, if the potential dose

saving at a particular location was expected to be less than the lower ERL for a countermeasure, then the Board would not recommend inclusion of that countermeasure for that location in the emergency plan. Similarly, if the expected dose saving was above the relevant upper ERL, then the Board would, in general, recommend that provision should be made either for that countermeasure or, if appropriate, for a more protective one, in the emergency plan[1]. For dose savings between the lower and upper ERLs, the decision whether or not to plan for the countermeasure would depend upon issues of practicability, the availability of other countermeasures which could equally well protect the public, and the need to develop a single plan for responding to a range of accidents. In particular, it is important that the plan reflects demographical boundaries so that anxiety within the affected population is not increased unnecessarily (eg individuals in small communities should all be advised to take the same protective actions). Flexibility in the application of the upper and lower ERLs is also important, since the plan should provide an adequate response for a range of accidents and circumstances. As explained in paragraph 11, in the development of emergency plans the upper and lower ERLs should never be interpreted in a rigid or precise manner, but as general guidelines[2].

Setting site specific ALs

28 Once a generally appropriate response for a range of accidents has been identified, it is important that the circumstances which should trigger this response are clearly identified. This is the role of site specific ALs. As discussed earlier, the Board does not intend that site specific ALs should be directly related to the ERLs. The ERLs are used to determine the broad response contained in the plan. The purpose of site specific ALs is to trigger the implementation of part or all of the emergency plan. Since this plan has been developed for a broad range of accidents and circumstances, the doses saved by implementing the plan will vary, depending upon the actual accident. However, site specific ALs will remain the same, and, at least initially, the plan will be implemented in the same way for any of these accidents and circumstances. It is clear therefore that if an accident occurs at a site for which a detailed emergency plan exists, then it is these site specific ALs, and not the Board's ERLs, which would initially trigger the implementation of countermeasures.

29 In determining site specific ALs it is important to take account of two factors. First, it may be useful to distinguish between a trigger to alert the emergency response organisations and a trigger for the initiation of countermeasures themselves. In this case, site specific ALs should be clearly and unambiguously specified for both types of trigger. Second, in the early stages of an accident, an appreciation of the progression and likely impact of the accident will necessarily be incomplete. It is therefore important that all those with responsibility for emergency response have confidence that the site specific ALs will trigger an appropriate response. Basing the emergency plan on a thorough evaluation of a range of possible accidents, as described above, will help to establish this confidence.

30 Site specific ALs may be expressed in a variety of units (in fact, they need not be numerical levels at all, so long as they are directly observable). The Board strongly recommends the consideration of precautionary countermeasures, and, for these, site specific ALs based on onsite measurements or plant conditions are likely to be important. However, it is also important to develop site specific ALs that relate to the period of the

accident when offsite monitoring is becoming available, for example offsite dose rates and air concentration measurements.

Limitations to the emergency plan

31 The emergency plan provides a robust framework for emergency response in a wide range of situations. However, it would be neither reasonable nor practicable to plan in detail for every conceivable accident, particularly those judged to be very improbable. In order to provide some early warning to those responding in the event of accidents not covered by the emergency plan, circumstances that would require a significantly different or enlarged response should be identified within the plan. This is particularly important if it is likely that the response defined by the plan would actually be prejudicial to the local population in certain circumstances. It is inappropriate for the plan to address these unlikely situations in detail, but they should be flagged. As discussed in paragraph 36, in general the upper ERL would be the more appropriate criterion to use in outline planning for such circumstances.

RESPONSE TO AN ACCIDENT

Urgent response

If an emergency plan exists, follow it

32 Since one purpose of an emergency plan is to reduce the time taken to implement urgent countermeasures, there must be a commitment by all those involved in the implementation of the plan to follow it, should an accident occur. It may be recognised, with hindsight, that a better response could probably have been devised, but it is likely that if this ideal response were sought at the time of the accident, a delay would be introduced which would result in a lower level of protection of the public than that provided by the emergency plan. Since the plan is developed in advance of any accident, its development is not subject to the time pressures existing in an emergency. It is likely that the detailed considerations which contributed to development of the plan will have been more comprehensive and thorough than any discussions could be about the best response in the immediate aftermath of an accident. Therefore, there should be no reason to delay implementation of the emergency plan in the immediate aftermath of an accident.

33 It also follows that if an accident occurs at a site for which an emergency plan has been developed, urgent countermeasures will initially be activated by the site specific ALs. Therefore, where an emergency plan exists, the Board's ERLs do not have a significant role during the early times following recognition of an accident.

Modifying the emergency plan

34 Once the most urgent countermeasures have been carried out or, at least, initiated, and as more information becomes available, it is reasonable to reappraise the response defined in the emergency plan and consider whether it should be modified. Such reappraisal will not delay countermeasures which need to be taken urgently, but, as detailed information becomes available, it will enable better estimates of the impact of the accident and possible countermeasures to be made. The doses estimated to have been averted by the countermeasures actually taken can be compared with the ERLs to provide a perspective on the level of protection achieved. Similarly, the averted doses anticipated for possible additional countermeasures can be compared with the ERLs, to

form one input to whether further countermeasures are appropriate. Again, the generic nature of the ERLs is emphasised; modifications to the response based on small (ie factors of two or three) deviations from the Board's numerical guidance would be most unlikely to be warranted (provided, of course, there was no likelihood of individuals suffering serious deterministic injuries).

35 Generally, decisions to modify the emergency plan during the course of an accident should only be taken if the planned response proves significantly inappropriate. Minor modifications to the plan would be likely to result in delays to the implementation of countermeasures, for very little, if any, increase in benefit. In particular, reducing the scale of the response, because it is subsequently thought to be an overreaction, is not advised, unless those responsible are certain that there is no further threat of release. Such a reduction could cause confusion, and would certainly undermine the confidence of the public in the ability of the authorities to manage the situation. Moreover, while a release is continuing, or further releases are threatened, it is prudent to maintain in force all countermeasures already implemented, in case the situation worsens. However, as discussed in paragraph 41, once the plant has been brought under control and there is no further threat of an uncontrolled release, then it is important to consider lifting countermeasures already in force, as countermeasures prolonged unnecessarily will reduce the overall benefit achieved.

36 If consideration of the actual impact of the accident and comparison of possible dose savings with the ERLs indicate that more widespread countermeasures should be taken than those indicated in the plans, then it is entirely appropriate that the planned response should be extended, or even altered altogether. In particular, this would be the case if the accident proved to be much larger than any scenario foreseen in the emergency plan. The timescale on which changes are implemented should reflect both practical considerations and the timing which is likely to achieve the best dose saving. Moreover, since the scale of response would be larger than that planned, it is likely that the comparison of potential dose savings should be made towards the upper end of the range indicated by the ERLs (ie it is most unlikely that extended implementation of a countermeasure would be justified at the lower ERL). The requirement to avoid serious deterministic injuries should also be considered.

If an emergency plan does not exist, use ERLs

37 In the unlikely situation that a serious accident occurs for which there is no site or contingency emergency plan which it is appropriate to activate (eg a damaged radioactive source in the possession of a member of the public, or a site accident that is very different from any of the accident scenarios considered when the emergency plan was developed), then it is necessary to adopt firm criteria for making initial decisions on the counter-measures needed. It is recommended that in these situations, the Board's ERLs and the third principle for intervention (avoidance of serious deterministic health effects) should be used. In the guidance that follows, it is recognised that the ERLs are being used in a slightly different manner from that described in the foregoing paragraphs. This is purely for pragmatic reasons: flexibility of application is most useful when there is time for proper reflection, particularly when emergency plans are being drawn up; it can be a hindrance when urgent decisions are required.

38 The first priority should be given to assessing the doses which have already been received (or committed from intakes already incurred). These doses should be estimated

quickly (and therefore very approximately). Any individuals judged to have received (or be committed to) an effective dose (or effective dose equivalent) of more than a few hundred millisieverts should, if practicable, be promptly removed from the possibility of further exposure from the accident, and a more accurate assessment of their exposures made. If necessary, personal decontamination and medical treatment should be provided for these individuals.

39 The second priority should be given to those most at risk from future (and therefore potentially avoidable) exposure from the accident. The projected effective doses (or effective dose equivalents), integrated from the time of the assessment for seven days (including the committed dose from intakes during the seven days), should be quickly (and therefore, again, very approximately) estimated. (The integration time of seven days is assumed as typical of the longest period for which evacuation, as opposed to relocation, would be considered. The choice of seven days in this particular application of the ERLs is partially arbitrary, and does not constitute Board advice on the appropriate integration time for doses to be compared with ERLs when emergency plans are developed; the appropriate time will vary between sites and different proposed implementations of countermeasures.) Where these exceed the *upper* ERL for evacuation, every effort should be made to remove the individuals concerned from the possibility of further exposure as quickly as this can be organised.

40 Once those most at risk have been identified and appropriate action taken, there should be a shift in priority from urgency to more detailed optimisation of the response. Further measurements should be taken to enable a moderate assessment of the situation to be carried out, in particular, the estimation of effective doses that would result from the implementation of different countermeasure options (including the decision to undertake no further countermeasures). From these, estimates of the doses avertable by different response strategies should be made. Decisions on countermeasures can then be taken in the light of available resources, the feasibility of the different options, and comparisons of the avertable doses with the ERLs.

Withdrawal of urgent countermeasures

41 It is important that urgent countermeasures are not prolonged beyond the time at which they are providing a net benefit. However, withdrawal of urgent countermeasures too quickly (eg when residual dose rates are high and falling rapidly) could result in individuals receiving additional doses needlessly. It is therefore important that plans include an appropriate monitoring programme which is implemented as soon as there is no further threat of release. This monitoring programme should be designed so as to provide, as efficiently as possible, the information necessary to make a prompt decision on the withdrawal of countermeasures.

42 Monitoring to inform decisions on the withdrawal of urgent countermeasures is best achieved by making a large number of rapid measurements of either outdoor dose rate or outdoor surface contamination.

43 The Board is currently developing guidance on criteria for return from evacuation, and more detailed guidance on the timing of withdrawal of advice to shelter.

Longer term response

44 In the longer term following an accident, there may be a need for continuing protective action, eg relocation of people away from the area for weeks, months or years,

and restrictions on individuals' lifestyles and activities. Since this longer timescale is not part of the emergency phase of the accident response, it is not discussed further here. In general, detailed planning for this longer term response would not form part of an emergency response plan. However, it should be recognised that there will be substantial pressure on those responsible for responding to the accident to provide early advice on the longer term implications. The monitoring programme implemented to inform decisions on the withdrawal of urgent countermeasures should also help inform the longer term decisions. The Board's advice on such so-called recovery countermeasures is published elsewhere[10].

SUMMARY

45 This document offers guidance on how the Board's ERLs should be used in the development of emergency plans and in response to radiological emergencies. The ERLs are discussed in the context of generic ILs (and ALs), and site specific and post-accident ALs. The ERLs are generic ILs, and so their primary role is for use during the development of emergency plans. If an accident occurs, it is recommended that any urgent response should be triggered by the site specific ALs specified in the emergency plan. Subsequently, the ERLs may be used to determine whether major modifications to this response are necessary. Only in the unlikely situation of the occurrence of a serious accident, for which there was no emergency plan which could be activated, should the ERLs be used as direct criteria, and then only for determining the most urgent response.

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IDENTIFICATION AND INVESTIGATION OF ABNORMALLY HIGH GAMMA DOSE RATES

ABSTRACT

In the years following the accident at the Chernobyl nuclear plant, many organisations in the UK established their own automatic environmental radiation monitoring networks. Their aim is to detect and measure any increases that might be caused by a nuclear or other radiation accident. This is commonly achieved by comparing measurements of gamma dose rate with a predetermined reference level.

This paper presents a generic protocol for establishing 'abnormality thresholds' of measured gamma dose rate, above which results may be considered unusual. Guidance on investigating abnormal dose rates is also given.

PREPARED BY D CLAHANE, N P McCOLL AND P H BURGESS

INTRODUCTION

1 In the years following the accident at the Chernobyl nuclear plant, many organisations in the UK, particularly local authorities, established their own local automatic environmental radiation monitoring networks, hereafter referred to simply as automatic monitoring networks. Their aim is to monitor environmental radiation levels in order to detect and measure any abnormal increases that might be caused by a nuclear or other radiation accident. This is most commonly achieved by comparing measurements of gamma dose rate with a predetermined reference level. Automatic monitoring networks may report elevated levels of gamma radiation for a variety of reasons. The majority of these arise from sources of radiation that do not present a hazard to the public. This paper presents a generic protocol for establishing 'abnormality thresholds' of measured gamma dose rate, above which results may be considered unusual. The protocol also gives guidance on investigating reports of abnormal dose rates.

AUTOMATIC MONITORING NETWORKS

2 Automatic monitoring networks have been introduced by organisations in many countries around the world and range widely in size and complexity: from a single monitor linked to a personal computer through to national monitoring networks with sophisticated radiological monitoring capabilities often coupled with predictive weather and radiological impact assessment tools.

3 The majority of local automatic monitoring networks consist of a number of radiation detectors distributed within a particular region, in communication with a central, controlling, computer system. The most common radiation detectors are compensated Geiger–Müller tubes used to measure gamma dose rate, usually fixed in a vertical orientation about 1 m from the ground and housed in a weather-proof cover. They are normally connected to a local data logger under microprocessor control whose features may include self-diagnosis routines for fault detection and identification, temporary storage of accumulated data, and automatic recognition when preset levels are exceeded. The monitoring sites themselves may be chosen to cover population centres, or be chosen for uniform coverage of an area or on the basis of practical siting issues such as security, land ownership and electrical power availability.

4 Automatic or 'online' systems do not require their monitoring measurements to be entered manually into the controlling computer system and some are rapidly approaching the provision of 'real-time' access to results. Generally, the detector and data logger 'outstations' either automatically dial up or are dialled by the central computer to report the most recently accumulated results. Communications usually involve a modem and serial data link via public or leased telephone lines. The exact frequency of reporting is a characteristic of individual systems. Monitoring results may be stored in the data logger and transferred hourly or, to reduce communications costs, daily or at intervals in between. If a predetermined alarm level is exceeded, outstations may be polled more frequently, to a minimum of about five minute intervals subject to the radiation detector and system type.

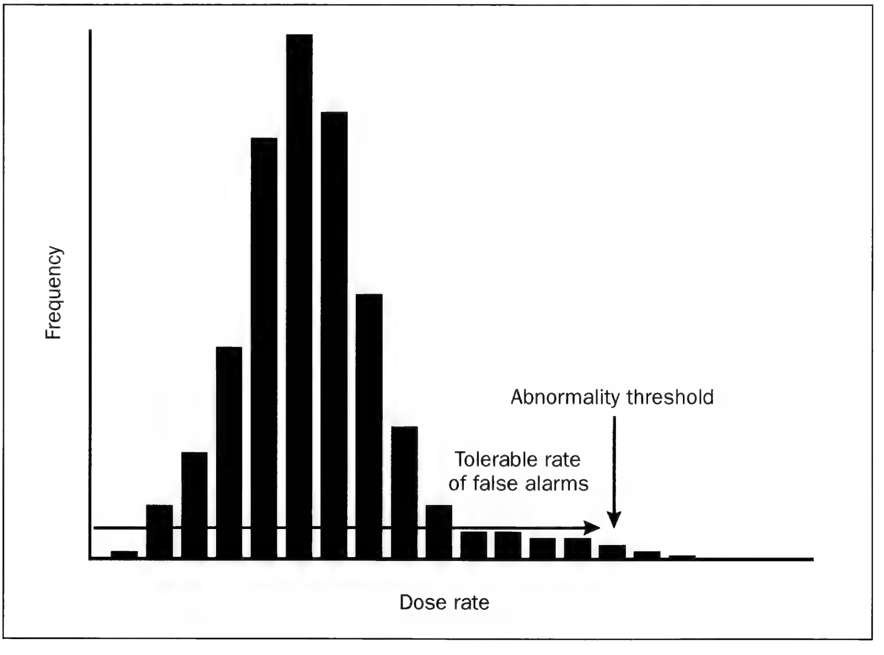
CAUSES OF ABNORMAL RADIATION LEVELS

5 Background gamma dose rates measured by automatic monitoring networks vary with detector location and with time. Across the UK the range of average background photon dose rate spans at least 50–120 nanogray per hour ($nGy\,h^{-1}$)[1], of which typically about 30 $nGy\,h^{-1}$ arises from cosmic radiation[2]. Individual gamma dose rate measurements depend upon local variations, caused mainly by site influences such as geology and altitude, temporal variations such as the season and the weather conditions, and characteristics of the detector such as sensitivity and inherent background. Short-lived elevations in gamma dose rate may occur naturally because of the deposition, during heavy rainfall, of the radioactive decay products of radon gas – a phenomenon known as radon washout. Observations have shown that, for a few hours, radon washout can substantially increase the local gamma dose rate[3]. Over time, the statistical nature of these variations tends to produce a distribution of observed dose rate with a single central peak such as that shown in Figure 1.

6 The compensated Geiger–Müller detector used in most automatic monitoring systems does not distinguish between individual sources of gamma dose rate. Therefore, prior knowledge of the normal variations in local background gamma dose rate is necessary to identify the presence of additional gamma-emitting radionuclides from a nuclear or other radiation accident, or to confirm their absence. Automatic monitoring networks provide a reliable and effective means of continuously monitoring local gamma dose rates and therefore can, over time, provide a known range against which future changes may be compared.

7 In a serious radiation accident, perhaps involving an atmospheric release of radionuclides, gamma dose rates may rise in affected areas due to high levels of airborne and deposited radionuclides during and after the passage of the cloud of radioactive material.

FIGURE 1 *Typical frequency distribution of gamma dose rates measured by a static detector*



Very close to the accident site, gamma dose rates may exceed tens of thousands of nanogray (tens of microgray) per hour and may reach the millions of nanogray (milligray) per hour range in extreme cases. At greater distances, increases will be much smaller and correspondingly more difficult to detect. At some point, the additional gamma dose rate resulting from an accident will cease to be measurable as it is, effectively, 'hidden' by the natural background. More sensitive detection methods, such as high volume air sampling, may continue to detect the presence of released radionuclides at great distances. Thus, the addition to the dose rate must be a significant fraction of the normal background, perhaps tens of nanogray per hour, for an automatic monitoring network to detect confidently the additional gamma dose rate from an accident. However, natural phenomena, primarily radon washout, can cause increases of a similar scale. There is therefore no unique abnormality threshold which indicates the influence of an incident and system operators must strike a balance between setting a low or high abnormality threshold. Setting a low threshold of gamma dose rate, above which any results are to be considered abnormal, will increase both the likelihood of reporting nuclear and other radiation accidents and the probability of false alarms due to natural and other events. A higher threshold value will be exceeded less frequently but will require an accident to generate higher gamma dose rates in order that an abnormality is reported. As the various natural and man-made events that might cause increases in gamma dose rate cover ranges that substantially overlap, the process of establishing the abnormality threshold depends on a prior knowledge of the natural variation and a decision made by the system operators on the acceptable rates of false alarms and of failure to identify genuine incidents.

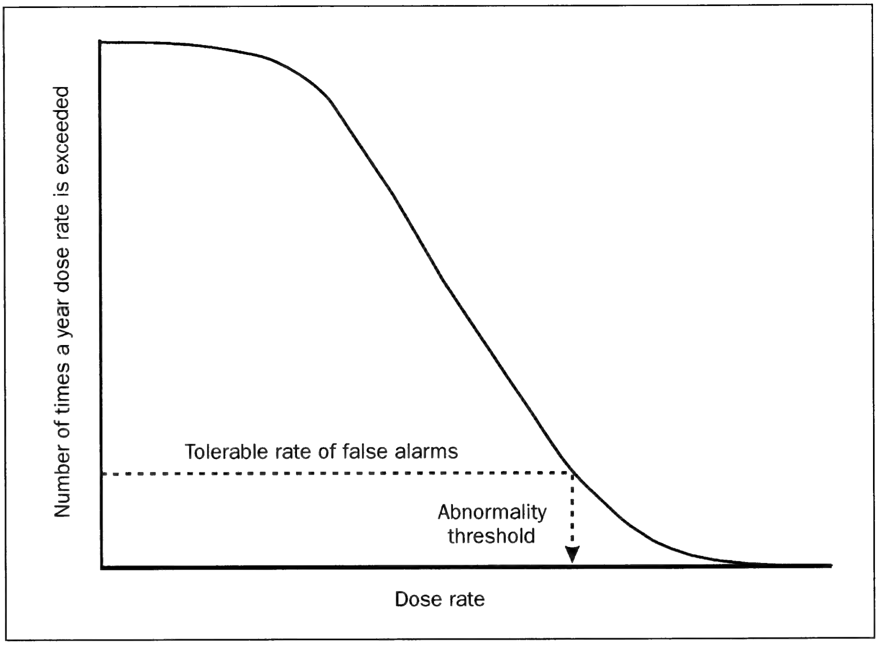
ESTABLISHING ABNORMAL GAMMA DOSE RATE THRESHOLDS

8 The protocol given in the table is suggested as a basis for establishing levels of gamma dose rate which could be considered to be abnormal for a particular automatic monitoring network outstation and would therefore warrant further investigation. It assumes that all equipment is operating correctly and that normal operational measurement periods (typically hourly), as specified by the system suppliers, are used.

Suggested protocol for determining an abnormality threshold

Step	Description
1	Local fluctuations in background gamma radiation levels should be determined by monitoring and retaining records of measured gamma dose rates at each monitoring location for at least a year. Beyond this, an increasingly accurate statistical picture of local conditions will be produced
2	The gamma dose rates observed over this period should be plotted graphically as a frequency distribution curve, as illustrated in Figure 1. From this the cumulative distribution can also be plotted, as illustrated in Figure 2
3	The tolerable annual rate of false alarms caused by natural events should be independently decided
4	This tolerable false alarm rate should then be identified on the frequency distribution curve and the gamma dose rate abnormality threshold set at the dose rate that intersects with the distribution curve at the corresponding frequency, as illustrated in Figure 1. Alternatively, the tolerable rate can be found from the cumulative distribution as illustrated in Figure 2

FIGURE 2 *Typical cumulative distribution of gamma dose rates measured by a static detector*



9 For a variety of reasons the plotted frequency distribution may not approximate to a single peaked distribution. In particular, there may be additional, smaller isolated peaks at the high end of the distribution. The causes of these are most probably natural events. However, if anomalies such as these are known to arise from equipment faults or other causes which the operator would wish to investigate should they recur, then these should be disregarded when determining the abnormality threshold.

10 Following this protocol should result in the selection of an abnormality threshold that will allow the efficient detection of an abnormally high gamma dose rate but should not cause an unacceptable number of false alarms resulting from normal fluctuations in background radiation. As the abnormality threshold is likely to be established within the broad range of natural background gamma dose rates observed across the UK, the risks arising from measured gamma dose rates around this level will be similar and should not be of concern to operators of monitoring networks.

INVESTIGATING ABNORMAL RADIATION LEVELS

11 As discussed above, a variety of situations might result in one or more radiation monitors reporting abnormally high gamma dose rates and some of these will have been considered when establishing abnormality thresholds. Two of the most likely causes of abnormal gamma radiation levels are radon washout and equipment faults. These and other possible causes are listed below:

(a) radon washout,
(b) detector or system fault,
(c) localised source of radiation,
(d) nuclear or other radiation accident.

12 This list is not exhaustive. Indeed, the cause of some temporary anomalies may never be discovered. Radon washout is almost always associated with heavy rainfall and occurs under atmospheric conditions which are both infrequent and not readily predictable. In the absence of other pertinent information, such as certain knowledge of the occurrence of a radiation accident, localised or widespread increases in gamma dose rate which are observed during periods of heavy rainfall are most likely to be the result of radon washout.

13 Abnormal dose rates which are not believed to be caused by radon washout should be investigated. Confirmation of reported abnormal dose rates should be sought through additional monitoring near at least one affected location, most probably using hand-held instrumentation calibrated similarly to the installed detectors. At this stage, detector or system faults should be successfully identified. If equipment faults are not believed to be the cause and measurements fall rapidly below the abnormality threshold before confirmatory monitoring is carried out, the cause could be considered a temporary anomaly. Local investigations may yield an explanation (see below).

14 If abnormally high gamma dose rates are confirmed by additional local monitoring then a new source of gamma radiation is likely to be present. If elevated measurements are reported at a single monitoring site, a likely explanation may be the local use or presence of a radiation source. Further investigations in the area immediately surrounding the monitoring site may be undertaken, helped if necessary by hand-held monitors. A

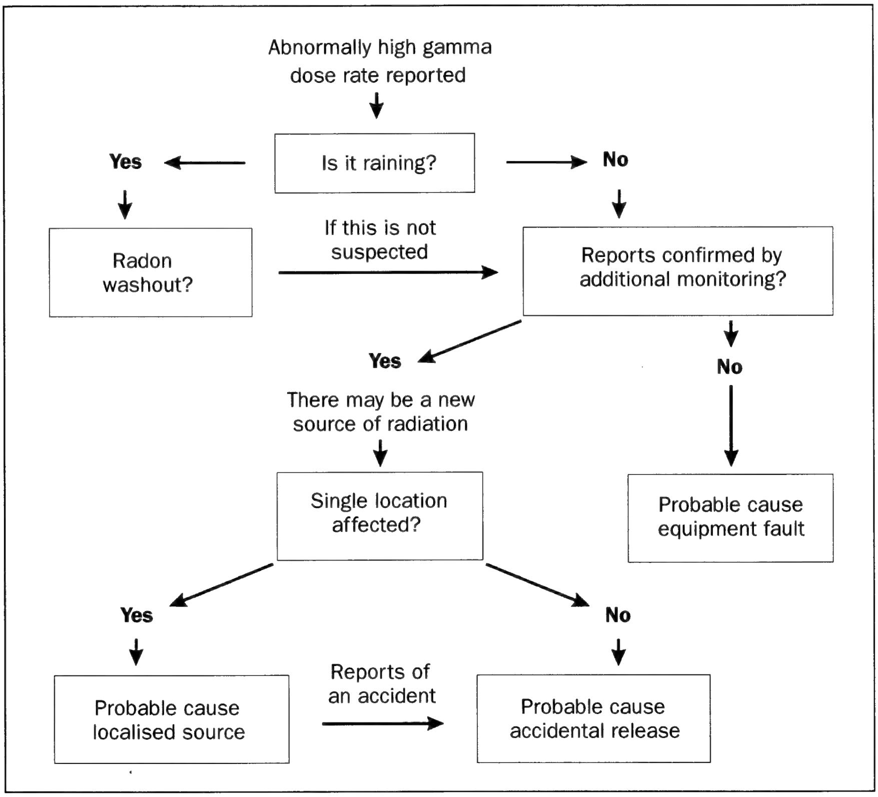


FIGURE 3 *Suggested investigation protocol*

possible cause could be local industrial activities involving ionising radiation, such as site radiography. If confirmed and abnormally high gamma dose rates are supplemented by reports of a nuclear or other radiation accident which could plausibly have led to local airborne or ground contamination then this may be the cause. Figure 3 summarises the logical sequence outlined above.

EMERGENCY RESPONSE ARRANGEMENTS

15 It is important to note that automatic monitoring networks do not, by themselves, provide sufficient information for the formulation of advice on urgent actions to protect the public, such as sheltering or evacuation or longer term measures such as restrictions on the sale of contaminated foods. For serious accidents which might require these measures, detailed national and local arrangements exist[4,5]. Through these arrangements, advice on actions necessary in the UK to protect the public would be provided to relevant local bodies. Users of smaller sources of ionising radiation must also formulate contingency plans to respond in the event of an accident[6]. These are supplemented by the National Arrangements for Incidents involving Radioactivity (NAIR)[7] through which the civil police can obtain expert assistance when a public radiation hazard is thought to exist and other emergency plans fail.

CONCLUSIONS

16 The gamma dose rates measured by automatic monitoring networks fluctuate according to natural and man-made influences. The additional gamma dose rate arising from a nuclear or other radiation accident may lie within this range as may legitimate, safely controlled, uses of ionising radiation in the environment. The operators of automatic monitoring networks should establish abnormality thresholds of gamma dose rate. Dose rates above this level would be regarded as unusual. In doing this, account should be taken of the variation in normal background at each monitoring site. A protocol for establishing abnormality levels has been outlined. Once these thresholds have been established, any abnormally high gamma dose rates should be investigated to identify their cause. A generic basis for these investigations has also been suggested.

17 Modern digital communications allow monitoring data to be shared, usually through proprietary software granting access to a central computer system. Remote access software includes the Radioactive Incident Monitoring NETwork (RIMNET) Remote Supplementary Data Entry (RSDE) software available to approved RIMNET data suppliers, and the access software associated with other monitoring network suppliers. Monitoring information collected by automatic monitoring networks will be of great value in the formulation of a national 'picture' of the effects of any future radiation accident, as well as providing a reliable basis for informing the public about local radiation levels.

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